Further evidence that Whorfian effects are stronger in the right visual field than the left

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Contributed by P. Kay, November 20, 2006 (sent for review September 19, 2006)

The Whorf hypothesis holds that differences between languages induce differences in perception and/or cognition in their speakers. Much of the experimental work pursuing this idea has focused on the domain of color and has centered on the issue of whether linguistically coded color categories influence color discrimination. A new perspective has been cast on the debate by recent results that suggest that language influences color discrimination strongly in the right visual field but not in the left visual field (LVF). This asymmetry is likely related to the contralateral projection of visual fields to cerebral hemispheres and the specialization of the left hemisphere for language. The current study presents three independent experiments that replicate and extend these earlier results by using different tasks and testing across different color category boundaries. Our results differ in one respect: although we find that Whorfian effects on color are stronger for stimuli in the right visual field than in the LVF, we find that there are significant category effects in the LVF as well. The origin of the significant category effect in the LVF is considered, and two factors that might account for the pattern of results are proposed.

color categories | hemispheric lateralization | linguistic relativity | visual search

The Whorf hypothesis holds that semantic differences between languages induce differences in perception and/or cognition in their speakers (1). Much of the experimental work pursuing this idea has focused on the domain of color and has centered on the issue of whether linguistically coded color categories influence color discrimination (2–13). A new perspective has been cast on the debate by recent results of Gilbert *et al.* (14), which suggest that language influences color discrimination strongly in the right visual field (RVF) and less so or not at all in the left visual field (LVF). This asymmetry likely is related to the contralateral projection of visual fields to cerebral hemispheres and the specialization of the left hemisphere (LH) for language. It suggests that, within an individual, the Whorf hypothesis may be relevant for processing within one hemisphere and not the other. In consequence, under normal conditions, perceivers may view the world at once filtered through the lens of their language and not so filtered.

In the Gilbert *et al.* study (14), subjects were given a visual search task that required detection of a single target color among 11 identical distractors. The target differed from the distractors in hue, and it was either of a different named category from the distractors (e.g., a blue among greens) or it was from the same category as the distractors (one blue among examples of another blue). The target-distractor perceptual differences for between-category (also known as across-category) discriminations were no greater on average than for within-category discriminations, yet between-category discriminations were significantly faster, but only when the target occurred in the RVF. Because the RVF projects to the LH, which in most people is also the dominant hemisphere for language (15), it was concluded that the implicit use of lexical codes in the LH was probably the origin of the lateralization of what we will refer to as the "category effect" (faster across- than within-category responses). This interpretation was supported by the finding that a concurrent verbal interference task eliminated the category effect for RVF stimuli, whereas the RVF category effect was preserved with a concurrent spatial interference task.

We present here two bodies of independent corroborating evidence for the lateralized Whorfian effect summarized above. We first describe a reanalysis of color search data from an earlier study by Daoutis *et al.* (16). We then report findings from two new experiments that involve finding a target color against a uniform background. In all three cases, we find that across-category discriminations were made faster than within-category discriminations to a greater degree in the RVF than in the LVF. However, unlike Gilbert *et al.* (14), we do find a significant category effect in the LVF as well, albeit a much weaker one.

Results

Visual Field Effects in a Color Identification Task with Crowded Displays: Reanalysis of Daoutis *et al.* (16). Daoutis *et al.* (16) found that the time to determine whether a specified (i.e., target) color was present in a display of multiple objects was highly influenced by the categorical relationship between that color and distractor colors. Fig. 1*a* depicts the stimuli used: two triplets of colors, three greens (G1, G2, and G3) and a blue, purple pink set (B, Pu, and Pi), in the International Commission on Illumination (CIE) chromaticity diagram (u′ v′). The u′ v′ space was designed with the intent that equal distances in the space represent equal perceptual dissimilarities. Thus, the differences within each of the four pairs of adjacent stimuli (G1-G2, G2-G3, B-Pu, and Pu-Pi) are nominally all equal. During training, observers were shown sets of stimuli consisting of a target and distractor colors, with the target consistently identified. After the observers demonstrated that they could remember the target, they were tested on a visual search task, in which a display of 4, 16, or 36 stimuli was shown (Fig. 1*b*). The observer indicated as quickly as possible whether the target was present, with the target, in fact, present on only half of the trials.

Search speed is faster as the dissimilarity between target and distractors increases (17), and, for visual search tasks involving colored targets, search speed is influenced by the relative locations of the stimuli in color space (17). If the three stimuli are colinear (e.g., G1 G2 G3), searching for the middle stimulus is hard (G2 among G1s and G3s), but searching for either of the

Author contributions: G.V.D., P.K., T.R., R.B.I., A.F., and I.R.L.D. designed research; G.V.D. performed research; A.L.G. and A.F. contributed new reagents/analytic tools; G.V.D. and I.R.L.D. analyzed data; and G.V.D., P.K., T.R., R.B.I., A.F., and I.R.L.D. wrote the paper.

The authors declare no conflict of interest.

Abbreviations: CIE, Commision Internationale de l'Éclairage (International Commission on Illumination); LH, left hemisphere; LVF, left visual field; RT, reaction time; RVF, right visual field.

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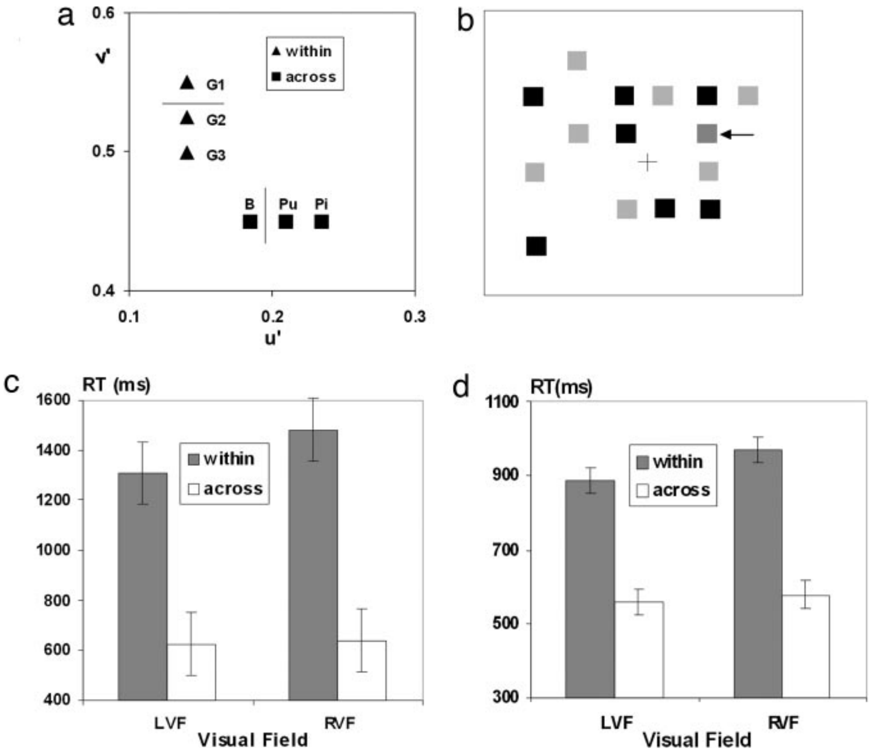

Fig. 1. The category effect is larger in the RVF than in the LVF in a reanalysis of the data from a color identification task used by Daoutis *et al.* (16). (*a*) Stimuli in CIE coordinates. The within-category set contains three hues of green: G1, G2, G3; the across-category set contains a blue (B), a purple (Pu), and a pink (Pi). Perceptual distance is the same for all adjacent pairs across both sets (G1-G2, G2-G3, B-Pu, and Pu-Pi). When a peripheral stimulus (e.g., G1) is the target, it is linearly separable from the distractors (G2 G3). (*b*) Illustration of a target-present trial with 15 distractors. The target is indicated here by the arrow that, however, was not present in the display itself. (*c* and *d*) Target detection times for within- and across-category targets by LVF and RVF: collapsed across linear separability (*c*) and linearly separable targets alone (*d*). Error bars show 95% confidence limits.

outside stimuli is easy (e.g., G1 among G2s and G3s). As a general rule, if the target can be separated from the distractors by a single straight line (G1| G2 G3 and B| Pu Pi in Fig. 1*a*) the target is "linearly separable" and the search is easy. If they are not, they are "linearly nonseparable" and the search is slow. The aim of the original Daoutis *et al.* study (16) was to see whether categorical separation of the three colors might mitigate this linear nonseparability effect. Experiment 1 compared search performance on the blue-purple-pink set with performance on the green set. For the green set, search for the middle color (G2) took more than twice as long as search for either of the peripheral colors (G1 or G3), whereas, for the categorically separate set, search for the middle color (purple) was no slower than the search for either blue or pink. This large attenuation of the effect of nonseparability also was found in a second experiment comparing a green-blue-purple set with a set of three blues equally separated in hue.

In these experiments, the target, when present, could occur in one of 32 locations. In the original analysis, the data were averaged across target locations. In the present reanalysis, we have considered trials only where the target was present and averaged separately across the 16 target locations to the left of the fixation point and the 16 target locations to the right of the fixation point. Four-factors repeated measure ANOVAs on linear separability (separable/nonseparable), category (within- or across-category), visual field (LVF/RVF), and number of distractors (4, 16, or 36) were performed on the experiment 1 and experiment 2 data. As in the original analysis, there were highly significant effects of linear separability, category, and their interaction for both experiments. Here, we only report statistics pertinent to the visual field effect.

Because the two experiments produced essentially the same pattern of results, we focus on the reanalysis of the data from experiment 1 of Daoutis *et al.* (16). As Fig. 1*c* shows, overall target detection in the LVF was ≈100 ms faster than in the RVF (1,018 ms as compared with 1,127 ms; $F(1, 7) = 17.71$; $P < 0.005$). This difference was largely due to the within-category condition, in which reaction time (RT) to targets was ≈200 ms slower in the RVF than in the LVF. Reaction times to targets in the two visual fields were more or less equal for the across-category case. Importantly, there was a significant interaction between visual field (LVF/RVF) and category (within- or across-category) [$F(1, 7) = 11.92$; $P < 0.01$], with a stronger category effect in the RVF than in the LVF. Put another way, the difference between the within- and across-category conditions was almost 200 ms larger for RVF targets than for LVF targets [$t(7) = 3.49$; $P < 0.01$], consistent with the lateralized Whorf effect observed in ref. 14.

Response times are much slower and the category effects are larger than those reported by Gilbert *et al.* (14). This may reflect the large impact of linear nonseparability on search times and the category effect. The category effect was larger for the nonseparable condition compared with the separable condition (≈300 ms compared with ≈60 ms) and the category × field × separability interaction approached significance [$F(1, 7) = 4.72$; $P = 0.07$] However, a secondary analysis of just the separable condition showed that the lateralization effect was not restricted to the nonseparable condition (Fig. 1*d*) The category × visual field interaction was again significant [$F(1, 7) = 5.57$; $P < 0.05$]: the category effect RT advantage was ≈60 ms larger for RVF targets than LVF targets [$t(7) = 2.49$; $P < 0.05$] and seven of eight observers showed this pattern. These response times and category effect are still larger than those reported by Gilbert *et al.*

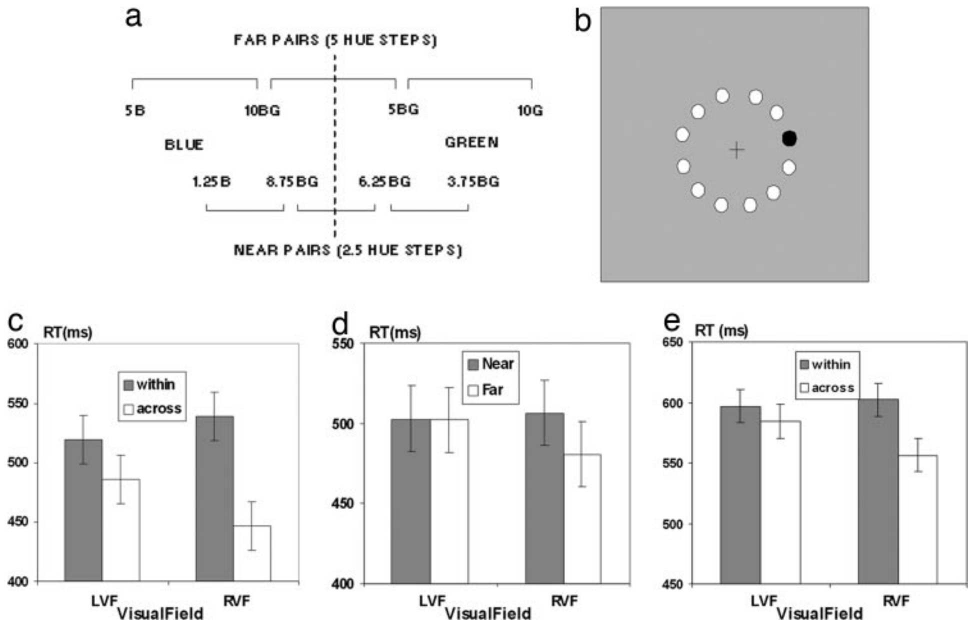

Fig. 2. A larger category effect is observed in the RVF on a color detection task. (*a*) Munsell codes of the stimuli; stimuli varied in hue at constant value and chroma. Hue separations were either five steps (far set) or 2.5 steps (near set). The target was either in the same color category as the background (e.g., 10BG on 5B, both blue) or in the adjacent category (e.g., 10BG on 5BG, blue on green). (*b*) Illustration of a test frame: white circles show possible target locations around the fixation cross, and the black circle representing the target. (*c* and *d*) Blue-green set: The difference in RT between within- and across-category is larger in the RVF (*c*). Target-background perceptual separation only affects the RVF (*d*). (*e*) Blue-purple set: Again, the difference in RT between within- and across-category is larger in the RVF. Error bars are 95% confidence limits.

(14), but much less so than with separable and nonseparable conditions pooled.

A similar pattern was observed in the reanalysis of experiment 2. Detection times in the LVF were ≈60 ms faster than those in the RVF [F (1, 11) = 12.36; $P < 0.005$], and the interaction between visual field and category was again significant [F (1, 11) = 6.98; $P < 0.025$], reflecting the larger category effect in the RVF than in the LVF [t (11) = 2.64; $P < 0.025$]. The size of the category effect in the nonseparable condition (≈140 ms) was again larger than for the separable condition (≈30 ms), but the category effect was still larger in the RVF than the LVF for the separable condition alone [F (1, 11) = 5.57; $P < 0.05$].

In both of these experiments, there is a stronger category effect for targets in the RVF than for targets in the LVF. The gain is mostly due to the relative slowness of detecting within-category targets in the RVF, given that across-category target detection took about the same time in both fields. It is noteworthy that, although the difference between the within- and across-category RTs was greater for the RVF, category effects were present in both visual fields. This observation differs from that reported in Gilbert *et al.* (14). In that study, the category effect was restricted to the RVF. The time required to detect within- or across-category targets was comparable in the LVF, but an RT advantage was present on across-category trials in the RVF (see figures 1*c* and 2*b* in Gilbert *et al.*; ref. 16).

The differences between the Daoutis *et al.* (16) and the Gilbert *et al.* (14) results may stem from differences in the corresponding tasks. The Daoutis *et al.* (16) observers first had to commit a color to memory and then search a display to see whether it was present. The Gilbert *et al.* (14) task had no memory component, requiring the observer to find a target color that was identifiable only by being different from 11 identical distractors. These task differences could have introduced any number of unseen factors. Also the Daoutis *et al.* (16) and Gilbert *et al.* (14) experiments differed in the former's including a target on only half the trials and in varying the number of distractors. Any of these differences may have contributed to the longer search times in Daoutis *et al.* (16) experiments.

The main conclusion we wish to emphasize here is that the reanalysis of the Daoutis *et al.* data (16) demonstrates a RVF relative advantage for across-category searches. Moreover, this applied to both separable and nonseparable searches despite considerable differences in their level of difficulty. This agrees with the Gilbert *et al.* (14) lateralization result and indicates the laterality effects may be quite general given the considerable differences in task. Note that the Daoutis *et al.* (16) study was not undertaken to test a lateralization hypothesis, and the lateralized effect was discovered only in post hoc analyses.

Visual Field Effects in a Color Detection Task with Sparse Displays. As part of a research program examining the development of categorical effects in color perception, Franklin *et al.* (8) developed a simple detection task that can be performed by infants. On each trial, a single circular target appears on a chromatically different, uniform background. In the initial infant study, detection time was measured by eye movements, taking advantage of the infants' natural inclination to look at the stimulus. In the current study, a manual response device was used instead, with the participants instructed to indicate whether the target was on the left or right by pressing a button with the corresponding index finger.

The target could appear in one of 12 locations arranged radially around the fixation cross, six to the left of fixation and 6 to the right of fixation, as in Gilbert *et al.* (14) (see Fig. 2*b*). The target differed from the background only in hue (constant value and chroma; see Fig. 2*a*) and was either in the same lexical category as the background (e.g., two blues: 5B, 10B; or two greens: 5BG, 10G) or in a different category (e.g., blue: 10BG; green: 5BG). The perceptual difference between target and background was the same, in Munsell hue units, in the within-category and across-category cases. As in the Gilbert *et al.* study (14), the size of the perceptual separation varied, with hue step sizes of either 2.5 or 5 (see Fig. 2*a*).

There were very few incorrect responses (≈4%). Median RTs for correct trials were calculated for each combination of category (within/across), perceptual distance (near/far), and visual field (LVF/RVF) for each observer, and these data were subjected to three-way repeated measures ANOVA. The only significant main effect was for category [F (1, 23) = 58.83; $P < 0.001$]. Across-category RTs were ≈60 ms faster than within-category RTs, indicating an overall category effect. As can be seen in Fig. 2*c*, there was also a strong interaction between category and visual field [F (1, 23) = 26.85; $P < 0.001$]. LVF targets were detected more quickly than RVF targets for within-category targets [t (23) = 1.98; P = 0.060, two-tailed]; for across-category targets, RVF targets were detected more quickly than LVF targets [t (23) = 4.95; $P < 0.001$]. There was a category effect for both visual fields, [minimum t (23) = 3.72; $P < 0.001$]; however, the size of the category effect (between faster than within) averaged 60 ms greater for the RVF than for the LVF [t (23) = 5.18 $P < 0.001$], and this held qualitatively for 22 of the 24 observers.

Perceptual distance had very little effect (see Fig. 2*d*). Targets with five-step separations were detected a modest 13 ms faster than those with 2.5-step separations, an effect that was marginally significant [F (1, 23) = 3.58; P = 0.07]. However, distance did interact with visual field [F (1, 23) = 4.49; $P < 0.05$] but not with category ($F < 1$). Five-hue step separations were ≈25 ms faster than 2.5 hue steps for the RVF [t (23) = 2.48; $P < 0.025$], whereas mean RTs for the two separations were virtually identical for the LVF. We do not have an explanation for this unexpected interaction.

With respect to the category–visual field relationship, these data mirror Gilbert *et al.*'s (14), with one exception. As noted above, in the Gilbert *et al.* study (14), a significant category effect (between faster than within) occurred only for RVF targets (although in each of the five conditions tested, LVF RTs showed a nonsignificant tendency in the same direction). In the present experiments, a significant category effect was found for both visual fields, with the effect larger for RVF targets than for LVF targets.

As a further test of the robustness and generality of the lateralization effect, we ran a second version of this detection experiment, using stimuli in the blue-purple region. Target-background pairs were either within-blue, within-purple, or between blue-purple. We only used separations of 2.5 Munsell hue steps, keeping value and chroma constant. Two-way ANOVA showed that the between-category search was ≈30 ms faster than within-category search [F (1, 33) = 25.8; $P < 0.001$] and that the interaction between visual field and category was significant [F (1, 33) = 5.94; $P < 0.025$]. Consistent with the blue-green results, the category effect was larger for the RVF than the LVF (Fig. 2*e*). The difference for the RVF was significant [t (33) = 6.07; $P < 0.001$], whereas the LVF difference was not significant [t (33) = 1.23; P = 0.23]. These results directly mirror those of Gilbert *et al.* (14), i.e., without the exception noted above.

General Discussion. Gilbert *et al.* (14) reported that a target color from a linguistic category distinct from that of distractors is found faster in the RVF than the LVF and, conversely, that a target color from the same named category as distractors is found faster in the LVF than the RVF. Because (*i*) each visual field projects to the contralateral brain hemisphere, (*ii*) the LH is known to favor language processing, and (*iii*) the lateralization effect was eliminated when concurrent demands were made on verbal, but not spatial, processing, Gilbert *et al.* (14) concluded they had isolated a Whorfian effect that was mostly or wholly restricted to the RVF/LH pathway. We report here that a similar effect is observed in two different color perception tasks, indicating that the laterality effect is quite general.

The first approach involved a reanalysis of the Daoutis *et al.* (16) data. Using a color identification task, it was found that the categorical relationship of a memorized target to distractors influenced visual search time, independent of purely perceptual factors (linear separability in color space). The side of the display on which the target color appeared (when present) was not analyzed in the initial study. When reanalyzed, as we have done here, these data show an interaction of visual field with across- versus same-category trials, with a stronger category effect in the RVF than in the LVF. This difference is driven by a RVF disadvantage for within-category trials.

The second approach consisted of two new experiments, employing a detection task. The task was similar to that used by Gilbert *et al.* (14) except that there were no distractor stimuli; rather, the target color was presented against a uniformly colored background, and the categorical relationship of the target and background was manipulated. Again, we observed an interaction of visual field with across- versus same-category trials, with the RVF showing a relative advantage in search speed for across-category trials. These results support the earlier finding (14) that the RVF/LH pathway is the primary locus of category effects in color cognition and/or perception.

Our methods differ from those of Gilbert *et al.* (14) in several important respects. We used somewhat different tasks, although they were also speeded visual search tasks, and we tested different category boundaries. We examined the blue/purple, blue/green, and purple/pink boundaries, whereas Gilbert *et al.* (14) only examined the blue/green boundary. Given these differences in task and stimuli, our finding of stronger category effects in the RVF than in the LVF constitutes a confirmation, and generalization, of the Gilbert *et al.* (14) findings. In contrast, there is another point of difference that does not merely confirm the earlier findings: Whereas Gilbert *et al.* (14) found significant category effects in the RVF but not the LVF, we find significant effects in both visual fields, but stronger effects in the RVF. This difference raises the question of the source of this weaker LVF category effect. There are at least two possibilities. One is that it is based, like the RVF effect, on linguistic information, but in this case that information must travel across the corpus callosum to the RH, and its influence may be attenuated because of this transfer. Another intriguing possibility is that the LVF category effect is of an entirely different character and, instead, reflects presumably universal categorical distinctions that are present even in prelinguistic infants (7–8). These possibilities can be discriminated by determining whether LVF and RVF category effects both vary with the speaker's native language.

Taken as a whole, our findings largely confirm, but also qualify, the proposal that Whorfian effects are lateralized to the RVF. More broadly, our findings strengthen the notion that considerations of brain organization, which traditionally have not been brought to bear on the Whorf hypothesis, may be relevant to that debate.

Materials and Methods

Color Identification Task. Full details can be found in Daoutis *et al.* (16).

Participants. There were 8 participants in the first experiment (5 women and 3 men; mean age 28 years) and 12 in the second (6 women and 6 men; mean age 26 years). They were all staff or students at the University of Surrey.

Equipment and stimuli. The stimuli were displayed on a calibrated 15-inch Sony Trinitron monitor, and the CIE coordinates were measured with a Minolta CS100 chroma meter. There were two sets of three stimuli for each experiment, a within-category set and an across-category set. Within each set, luminance was constant, the stimuli were colinear in CIE u′ v′, and the separation between adjacent pairs was 20 ΔE in CIE L*u*v*. In experiment 1 of Daoutis *et al.* (16), the within-category set was green (G1, G2, G3; CIELUV coordinates [u′ v′]: 0.1350 0.4980, 0.1350 0.5230, 0.1350, 0.5480 all at L* = 62.87) and the across-category set was blue, purple, and pink (B, Pu, Pi; 0.1800 0.4480, 0.2020 0.4480, 0.2220 04480, all at L* = 76.07, see Fig. 1*a*). In experiment 2, the within category set was blue (CIELUV: 0.1555 0.3744, 0.1604 0.3995, 0.1655 0.4244, at L* 68.75) and the across-category set was green, blue, and purple (0.1654 0.4581, 0.1819 0.4396, 0.1984 0.4218 at L* 68.75). Minimum naming reliability was 98%. In the linearly nonseparable conditions, the target was the middle stimulus (e.g., G2 and Pu, Fig. 1*a*), and in the separable conditions, it was one of the outside stimuli (e.g., G1 or G3 and B or Pi, Fig. 1*a*) used equally often. The distractors were the two nontarget stimuli. Each stimulus was 17 mm^2, and the stimuli on each trial were displayed in a notional six-by-six grid with 5-mm gaps between adjacent locations on the grid. The surround and the gaps were gray and darker than the stimuli. There were three set sizes: 4, 16, and 36. For set sizes 4 and 16, stimulus locations were randomly selected, whereas for set size 36, all locations were filled. For target-absent trials, there were equal numbers of the two types of distractors, but for target-present trials, a target replaced one of the distractors. Targets appeared equally often in all grid locations, except that the four corners were not used. Thus, there were 16 locations in each visual field.

Procedure. There were four conditions made up from the combinations of linearly separable/nonseparable and within-category target/across-category target. The order of the four conditions was counterbalanced. For each condition, the observer first was trained to identify the target color by exposing the target and distractors together, labeled as such, until the observer expressed confidence in being able to remember the target. After training, the search task was performed. There were 64 search trials for each display size, half target-present and half target-absent, and the order of trials was randomized. Each trial consisted of a central fixation cross for 250 ms, followed by a 400-ms blank interval, followed by the search display. The search display remained visible until a response was detected. The observer pressed one of two buttons on a computer mouse, indicating whether the target was present or absent. After the response, there was a 400-ms interval before the onset of the next trial.

Color Detection Task. ***Participants.*** There were 58 participants (50 female and 8 male, mean age 23 years). All were students at the University of Surrey and received course credit for their participation. They had normal or corrected-to-normal vision, and normal color vision as assessed by the City University color vision test (Fletcher, 1980), were right-handed, and were native English speakers. Twenty-four were tested with the blue-green set, and 34 were tested with the blue-purple set.

Stimuli and design. The stimuli were displayed on a Sony GDM-F520 505-mm monitor. A Cambridge Research Systems (Rochester, U.K.) Colorcal was used to obtain CIE coordinates.

Blue-green set: There were eight stimuli that varied only in Munsell hue at value 7 and chroma 8 in the range 5B to 10G as shown in Fig. 2*a*. Their CIELUV coordinates (u′ v′) were: far pairs 0.1464 0.4722, 0.1438 0.4598, 0.1447 0.4393, 0.1508 0.4210 and near pairs 0.1460 0.4349, 0.1445 0.4445, 0.1439 0.4550, 0.1443 0.4645; L* 62.51. These were chosen to provide a set of four blues and four greens with the boundary at ≈7.5 BG. We conducted a preliminary experiment to assess their linguistic classification. A rectangular stimulus (50 mm^2) was presented in the center of the monitor on a gray background, and participants labeled it as either blue or green. The stimulus was presented until a response was made. There were four repetitions of each stimulus and the 36 trials were in random order. The results confirmed that the blue-green category boundary was ≈7.5BG, with the most frequent responses to the four stimuli to the left and right of the boundary (Fig. 2*a*) being blue and green, respectively.

The target was a circle of 30 mm diameter (≈3.5° when viewed from 500 mm). It appeared on a colored background. The relationship between the target and background was manipulated in two ways. First, the two colors were either from the same category or from different categories. Second, the perceptual distance varied. In the "near" condition, the separation was 2.5 hue steps (ΔE = 9), whereas in the "far" condition, the separation was five hue steps (ΔE = 18; see Fig. 2*a*). For both the near and far conditions, there were three pairs of stimuli: one pair was across-category, one was within-green, and one was within-blue (see Fig. 2*a*). For each pair, one color was used for the background that filled the monitor and the other color was used for the target.

Blue-purple set: A preliminary naming experiment established that the blue-purple boundary was at ≈10PB at value 5 and chroma 10. Four stimuli were selected, two blues and two purples with separations of 2.5 hue steps (ΔE = 11) between adjacent pairs at constant value and chroma (6.25PB, 8.75PB, 1.25P, and 3.75P; CIELUV: 0.2213 0.3803, 0.2078 0.3730, 0.1924 0.3674, 0.1744 0.3654, at L* 49.36). Hue separation distance was not manipulated with this set.

Procedure. Participants were told that on each trial, the display would consist of a target color on a uniform background of a different color and that their task was to decide whether the target was to the left or right of the fixation cross as quickly as possible while maintaining high accuracy. The target could appear in one of 12 equally separated (30°) locations on a notional circle of 110 mm diameter around the fixation cross at the center of the monitor (≈12.5° from fixation) as illustrated in Fig. 2*b*. In clock face terms, six locations were in the RVF from 12:30 to 5:30 at hourly intervals and six were in the LVF (6:30 to 11:30).

A trial sequence consisted of a white fixation cross on a black background for 1,000 ms, followed by the test display for 250 ms, followed by a black screen that was terminated by the response. The cycle then repeated. Responses were made on a games pad (PCL RP100) with the left index finger indicating left and the right index finger indicating right. Reaction times were measured from the onset of the target display until a response was made. A high-resolution timer DLL (ExactTics) ensured accurate event timing.

For the blue-green set, there were 96 experimental trials made up from 16 trials of each of the six color pairs. For the blue-purple set, there were 96 experimental trials, 32 for each stimulus pair (within-blue, within-purple, and between-blue-purple). Each stimulus in a pair served for half the trials as the target and half as the background. For each pair, the target appeared on the left for half the trials and on the right for half the trials in randomized order. Within the latter constraint, target locations were chosen at random, but with the overriding constraint that each location was used equally often across each set of 48 trials for near and far conditions. There were 24 practice trials consisting of randomly chosen stimulus pairs followed by the 96 experimental trials. No feedback was given.

We are grateful to Christina Daoutis for help with the reanalysis of experiment 1. This research was supported by National Science Foundation Grants 0418404 and 0418283 and by a grant from the Economic and Social Research Council (to I.R.L.D.).

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